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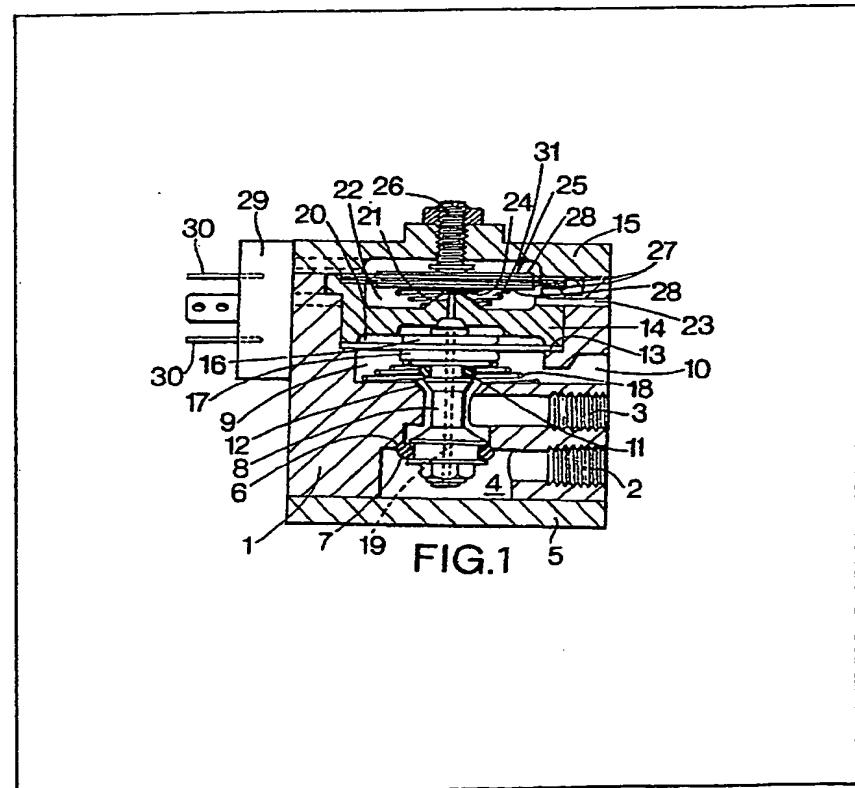
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(54) Fluid-operable valve or actuator therefor including a piezo-electric crystal actuating device

(57) A fluid-operable valve, including a chamber 20 containing a pressure-responsive member 13 arranged to move a valve member 8 in response to variation of fluid pressure within the chamber 20, the chamber 20 having a restricted inlet or outlet 21 for pressurised fluid, the inlet or outlet 21

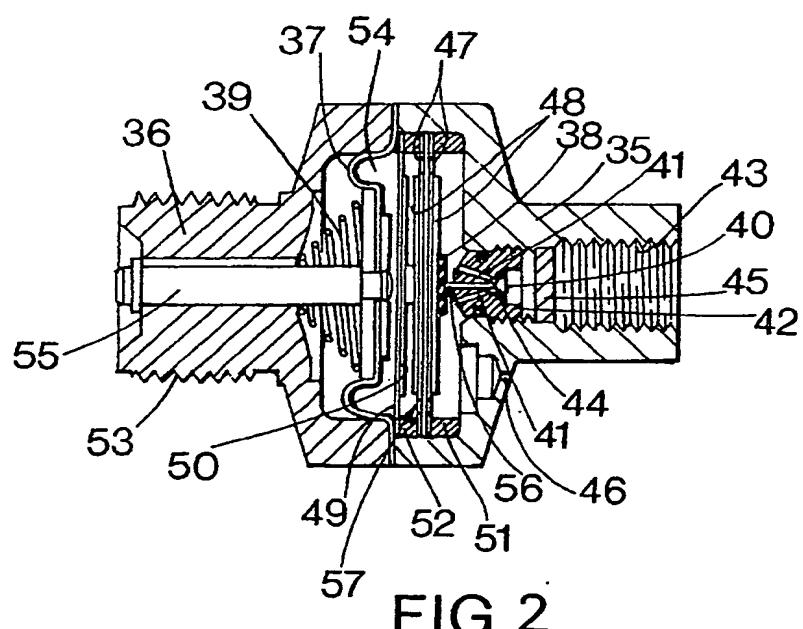
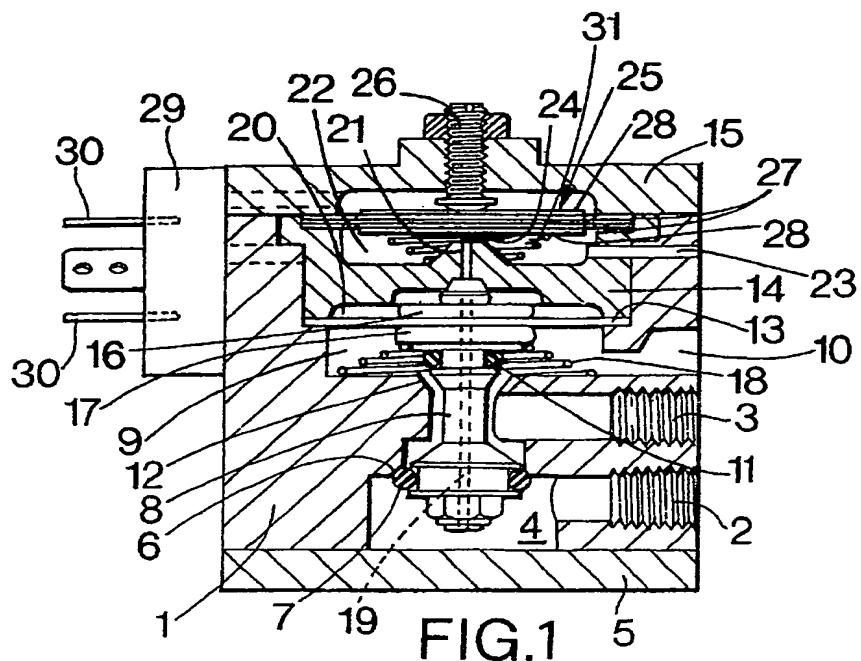
being openable or closable by a piezo-electric crystal device 25 connected to receive an electrical signal and thereby to move between first and second positions, in one of which the inlet or outlet 21 is open and in the other of which the inlet or outlet 21 is closed. Alternatively, the invention provides an actuator for a valve and in that case, the pressure-responsive member is arranged to move an actuating member arranged to move a valve member of a valve.



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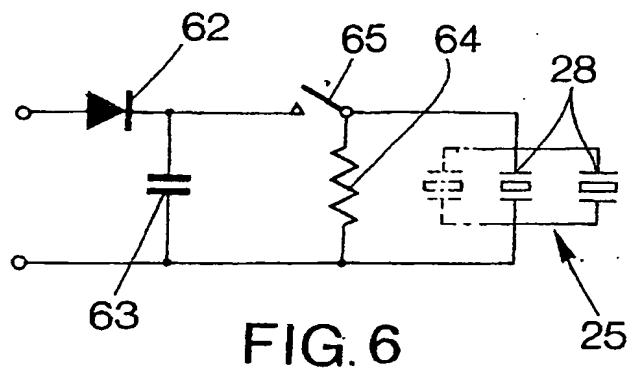
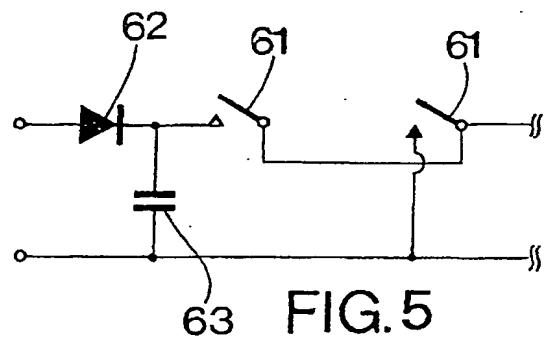
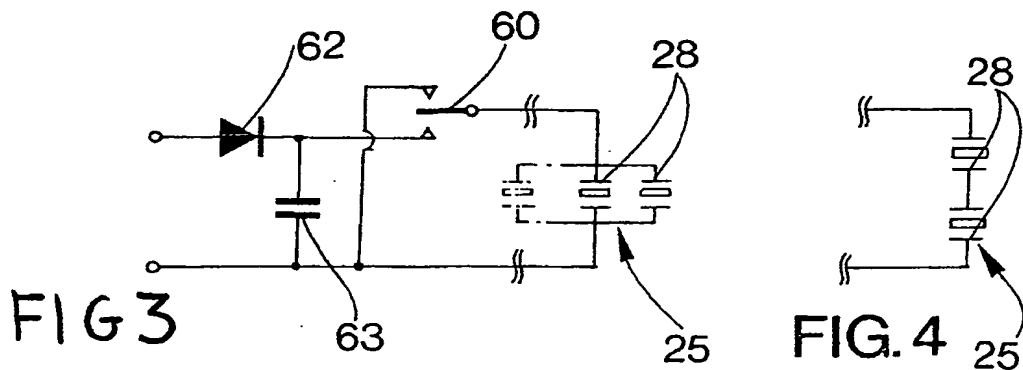
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SPECIFICATION**Fluid-operable valve or actuator therefor including a piezo-electric crystal actuating device**

- 5 The invention relates to a fluid-operable valve or actuator therefor arranged to be actuated by a piezo-electric crystal device.
- Electrically-operable fluid valves known hitherto are opened and closed by electro-magnetic devices, such as solenoids.
- 10 Piezo-electric crystal devices operable as electrical-to-mechanical transducers have been used to produce audio signals or as indicators by employing the deflection or voltage output produced by an input electrical signal but they have not been employed hitherto to actuate a fluid-operable valve.
- 15 According to the invention, a fluid-operable valve, or an actuator therefor, includes a chamber containing a pressure-responsive member arranged to move a valve member, or to move an actuating member for moving a valve member, in response to variation of fluid pressure within the chamber, the chamber having a restricted inlet or outlet for pressurised fluid, said inlet or outlet being openable or closable by a piezo-electric crystal device connected to receive an electric signal and thereby to move between first and second positions, in one of which the inlet or outlet is open and in the other of which the inlet or outlet is closed.
- 20 Conveniently, the piezo-electric crystal device is mounted to bridge the inlet or outlet at the mid-point of the device and is supported in the chamber at each side of said mid-point at equal distances therefrom, whereby the maximum deflection of the device will occur at the vicinity of the inlet or outlet.
- 25 Alternatively, the piezo-electric crystal device may be so mounted as to open or close the inlet or outlet indirectly. For example, a member may be positioned between the piezo-electric crystal device and the inlet or outlet, whereby the device will so move the member that the latter will open or close the inlet or outlet. For example, the member may be a lever. By arranging the respective positions on the lever of the points of contact therewith of said device and the inlet or outlet relative to the fulcrum of the lever
- 30 magnification may be achieved.
- 35 Two or more piezo-electric crystal elements may be superimposed one on the other to form a composite device in which the elements are connected electrically either in parallel or in series.
- 40 One convenient form of the piezo-electric crystal device is in the form of a disc-like substrate to each face of which a piezo-electric crystal ceramic is bonded.
- 45 By way of example a valve and an actuator in accordance with the invention are now described with reference to the accompanying drawings, in which:
- 50 Figure 1 is an axial section through the valve;

- 55 Figure 2 is an axial section through an alternative actuator, and Figures 3—6 illustrate alternative electrical circuits for operating piezo-electrical crystal devices to be employed in the valve of Figure 1 or the actuator of Figure 2.
- 60 Referring first to Figure 1, the valve comprises a block 1 having an inlet port 2 and an outlet port 3 communicating with a first chamber 4, closed at one end of the block 1 by an end-plate 5. The chamber 4 has an annular seat 6 therein between the ports 2 and 3 engageable by an O-ring 7 mounted on one end of a poppet valve member 8. The chamber 4 communicates with a second chamber 9 on the block 1 and also with an exhaust port 10. The flow-path between the ports 3 and 10 is controlled by an O-ring 11 mounted on the other end of the poppet valve member 8 and engageable with an annular seat 12. In one position of the poppet valve member 8, the seat 6 is open and the seat 12 is closed and in the other position, the seat 6 is closed and the seat 12 is open. The chamber 9 is closed above the seat 12, as viewed in Figure 1 by a diaphragm 13 clamped against the block 1 by an insert 14 held in an upper end portion of the block 1 by an upper end-plate 15. The end plates 5 and 15 are secured to the block 1 by through bolts (not shown). The diaphragm 13 is clamped by an upper central plate 16 to the upper end 17 of the poppet valve member 8 and is urged into the position illustrated in which the seat 12 is open and the seat 6 is closed by a helical spring 18. When the diaphragm 13 is pressed downwardly (as hereinafter described) against the spring 18, the seat 12 will be closed and the seat 6 will be opened. A fine bore 19 extends through the poppet valve member 8 to the upper end of the upper plate 16. The upper face of the diaphragm 13 defines with a depression in the lower end of the insert 14, a third chamber 20 (the chamber in the aforesaid statement of invention) which communicates through a bore 21 in the Insert 14 with a fourth chamber 22 leading to an exhaust port 23. The upper end of the bore 21 is arranged to be closed by a sealing pad 24 carried on the lower face of a piezo-electric crystal device 25 located between the insert 14 and the end plate 15. The upper face of the device 25 is engaged by an adjusting screw 26 in the end plate 15.
- 100 The device 25 is in the form of a disc, or pair of discs mounted back-to-back, of an electrically inactive substrate, e.g., brass 27 bonded on each face, if a single disc, or on one face only if there are two discs back-to-back, to a piezo-electric crystal ceramic disc-like element 28. The two elements 28 are connected in parallel through an electrical connector 29 to terminals 30 by which an electrical signal is applied to deflect the device 25. Application of a D.C. potential to the elements 28 causes a differential expansion of the two elements 28 of approximately 2.5×10^{-4} mm per volt per element. Thus the deflection at 100 V of the two elements connected in parallel is approximately $0.025\text{mm} \times 2 = 0.05\text{mm}$.

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In operation, the screw 26 is adjusted to engage the device 25, as illustrated, to leave a gap between the pad 24 and the upper end of the bore 21 when there is no electrical signal applied to the elements 28 such that when a signal of the required voltage is applied, the device will deflect at its centre to close the mouth of the bore 21. The disc or discs 27 are supported adjacent their peripheries and so the maximum deflection will occur at the centre. Before the electrical signal is applied to the elements 28, the spring 18 will hold the poppet valve member 8 in its illustrated position in which the seat 6 is closed by the O-ring 7 and there is no flow between the inlet port and the outlet port 3. Also in this position the pressure above and below the diaphragm 13 is atmospheric as the pressure from the chamber 4 communicates through the bore 19, the chamber 20, the bore 21, the chamber 22 with the port 23.

When the electrical signal is applied to the elements 28, the device will be deflected downward to close the bore 21. The pressure above the diaphragm will then increase to the inlet pressure in the chamber 4 and so the diaphragm 13 will press the poppet valve member 8 down to close the seat 12 by the O-ring 11 and to open the seat 6. There will therefore be a communication between the inlet port 2 and the outlet port 3 through the chamber 4.

When the electrical charge applied to the elements 28 is removed, the device 25 is returned to its original position, as illustrated, by a spring 31. Similarly, the spring 18 returns the diaphragm 13 together with the valve member 8 to their original positions, as shown in Figure 1.

The valve shown in Figure 1 is intended to be used as a pilot valve to control via the ports 2, 3 and 10 a main valve (not shown).

The actuator shown in Figure 2 comprises two body portions 35, 36, which are clamped together with a roll diaphragm 37 therebetween. The roll diaphragm 37 carries an actuator pin 55 which passes through a bore in the body portion 36. The roll diaphragm is urged to the right, as viewed in Figure 2 by a spring 39. In this position the actuator pin 55 is retracted wholly within the body portion 36. When the roll diaphragm 37 is pressed to the left, as viewed in the Figure, as hereinafter explained, the actuator pin 55 will extend from the body portion 36 to effect actuation of another device (not shown) such as a valve member of a main valve. The roll diaphragm 37 defines with a cavity within the assembled body portions, 35, 36 a chamber 54 (the chamber in the aforesaid statement of invention). The body portion 35 also contains a piezo-electric crystal device which carries a pad 38 which engages a pin 56 of a poppet valve 40 controlling the flow of pressurised fluid through fine bore throughways 41 in a valve insert 42 which is screwed into a threaded socket 43 in the body portion 35. The head of the poppet valve 40 is engageable with an O-ring seat 44 in the insert 42. The socket 43 contains a filter 45 and receives a pipe connector supplied with pressurised fluid. When the device

57 is in the normal position illustrated, corresponding, usually, to no electrical signal applied to the device 57, the pad 38 allows the poppet valve 40 to be held by the fluid pressure at the inlet socket 43 in the closed position. When the device 57 is deflected by the application of the electrical signal to the device 57, the device 57 moves to the right, as viewed in Figure 2 and so pushes open the poppet valve 40. This permits pressure fluid to flow through the throughways 41 and enter the chamber 54 through holes in, or by flowing around, the device 57. This application of pressure results in movement of the roll diaphragm 37 to the left, thereby causing the actuator pin 55 to move to the left and thus to protrude from the body portion 36. When the electrical charge is removed, the device 57 will return to the illustrated position, the poppet valve will close and the spring 39 will return the roll diaphragm 37 and the actuator pin 55 to their illustrated positions. Return movement of the roll diaphragm 37 is permitted by the exhaust of pressurised fluid in the chamber 54 from a fine bore bleed or vent 46.

The device 57 is similar to the device 25 shown in Figure 1 in that it comprises two discs 47 carrying piezo-electric crystal ceramic layers 48. The device 57, however, has a third disc 49 attached to but spaced from the discs 47 and carrying a third piezo-electric crystal ceramic layer 50. The discs 47 and 49 are located at their peripheries between resilient spacer rings 51, 52. The body portion 36 has an external screw thread 53 by which the actuator can be screwed into a main valve in place of an actuator of another type.

Although in Figures 1 and 2, each piezo-electric crystal device is supported at its periphery and engages the inlet or outlet at its centre, the piezo-electric crystal device may engage a lever which in turn engages the inlet or outlet. By arranging the points of contact of the said device and the inlet or outlet with the lever at different distances from the fulcrum amplification can be obtained.

The valve of Figure 1 and the actuator of Figure 2 are fluid-operable e.g. pneumatic; but other pressurised fluid may be used to effect movement of the pressure-responsive member, i.e., the diaphragm 13 or 37, as a result of actuation of the piezo-electric crystal device 25 or 57.

The electrical connections to the piezo-electric crystal elements 28 (or 48, 50) are shown in Figures 3—6 and, as already stated, the elements, where there are two or more in a piezo-electric crystal device, may either be connected in parallel, as in Figures 3 and 6, or in series, for higher voltages, as in Figure 4.

The devices 25 and 57, by virtue of their construction in superimposed discs also form capacitors and so are able to hold an applied D.C. charge for a considerable time which could be several hours, although switching and wiring insulation losses could reduce the time to minutes. This capacitive property means that the devices are bi-stable. Thus after charging with a short

- duration pulse of say 110 V, the valve or actuator will remain in the state to which the device has set it for an appreciable period, which may be twenty minutes or more according to the standard of
- 5 insulation applied to the switching. Normally for bi-stable operation a two-way switch would be required to enable a quick discharge to be applied to the elements of the device to restore the valve or actuator to its original state. Switching circuits for bi-stable operation of the devices are shown in Figures 3 and 5. In Figure 3 a two-way single switch 60 is used while in Figure 5, two on/off switches 61 are used to produce the same bi-stable operation.
- 10 With a simple circuit including a diode 62 and a capacitor 63 in parallel with the device 25 or 57, as shown in Figures 3, 5 and 6, the devices will operate with electrical signals applying 90 V or more. The electrical signal may be D.C. or A.C.
- 15 Where the applied voltage is lower, e.g. 24 V a small transformer would be required. Figure 6 shows a circuit including a resistor 64 in parallel with the capacitor 63. A single on/off switch 65 is closed to actuate the elements 28 and is opened
- 20 to restore them to their original positions for mono-stable operation, the capacitive charge in the elements 28 thus leaking through the resistor.
- The use of the piezo-electric devices for operating a valve or actuator, in accordance with
- 25 the invention, gives the following advantages:
1. There is negligible current consumption. This is less than 10mA and therefore the devices are able to work with the power levels produced by electronic logic circuits.
 - 30 2. No appreciable heat is developed by the devices and thus there are no problems of ventilation as there are when using banks of solenoid valves.
 3. One device can operate over a wide range of input voltage, either D.C. and A.C., the actuating circuit therefore including one diode only.
 - 40 4. There are no windings, as in solenoids, which would burn out or fail as a result of winding stress, except where the input voltage is low where a coil may be required. Therefore the devices are more reliable than solenoid-operated valves and the like.

CLAIMS

- 50 1. A fluid-operable valve or an actuator

therefor, the valve or actuator including a chamber containing a pressure-responsive member arranged to move a valve member, or to move an actuating member for moving a valve member, in response to variation of fluid pressure within the chamber, the chamber having a restricted inlet or outlet for pressurised fluid, said inlet or outlet being openable or closable by a piezo-electric

- 55 crystal device connected to receive an electric signal and thereby to move between first and second positions, in one of which the inlet or outlet is open and in the other of which the inlet or outlet is closed.
- 60 2. A valve or actuator as claimed in Claim 1 in which the piezo-electric crystal device is mounted to bridge the inlet or outlet at the mid-point of the device and is supported in the chamber at each side of said mid-point at equal distances therefrom, whereby the maximum deflection of the device will occur at the vicinity of the inlet or outlet.
- 65 3. A valve or actuator as claimed in Claim 1 in which the piezo-electric crystal device is so mounted as to open or close the inlet or outlet indirectly.
- 70 4. A valve or actuator as claimed in Claim 3 in which a member is positioned between the piezo-electric crystal device and the inlet or outlet, whereby the device will so move the member that the latter will open or close the inlet or outlet.
- 75 5. A valve or actuator as claimed in Claim 4 in which the member is a lever.
- 80 6. A valve or actuator as claimed in any preceding claim in which the piezo-electric crystal device comprises two or more piezo-electric crystal elements superimposed one on the other to form a composite device in which the elements are connected electrically either in parallel or in series.
- 85 7. A fluid-operable valve constructed and arranged substantially as described herein and shown in Figure 1 of the accompanying drawings.
- 90 8. An actuator for a fluid operable valve, the actuator being constructed and arranged substantially as described herein and shown in Figure 2 of the accompanying drawings.
- 95 9. A fluid-operable valve as claimed in Claim 7 or an actuator as claimed in Claim 8 including piezo-electric devices and electrical circuits therefor substantially as described herein with references to any one of Figures 3—6 of the accompanying drawings.

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